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§
FOR: **SUPERCONDUCTING ARRAY OF** §
SURFACE MRI PROBES §

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AMENDMENTS AFTER ALLOWANCE

Applicants just discovered in preparing the formal drawing that the figure numbering in the Detailed Description of the Invention of the Specification is incorrect. Applicants' attorney uses a counter and incrementers to increment that Figure numbers so that Figures are not used twice. Applicants' attorney failed to reset the counter after the Brief Description of the Drawings. The last figure was 12 and the first figures in the Detailed Description of the Invention was 12 and should have been 1.

Applicants are submitting are herewith including amendments to the specification to correct these incorrect figure numberings.

Applicants are also attaching a substitute specification (with and without correction marking) for the convenience of the Office.

AMENDEMENTS
In the Specification

[0056] Referring now to **Figures ~~12~~1A&B,** the difference in an electric field distribution between the two-sided resonator designs of this invention, generally **1**, and a single loop design, generally **150**, are shown. When a pair of properly aligned loops or coils **102a** and **102b** having a dielectric substrate **104** interposed between them, then the resulting electric field **106** is confined within the dielectric substrate **104** and does not extend above or below resonator **100**. Thus, such resonators 100 when used to image a body of an animal including a human, the generated electric field, being confined in the dielectric **104**, does not penetrate the body. A similar design principle has been used for single superconducting coils. On the other hand, in the single loop design **150**, the resulting electric field extends above and below the loop **150** and will penetrate into a body when used as an imaging resonator.

[0058] Referring now to **Figures ~~13~~2A-C**, a preferred embodiment of a single resonator of this invention, generally **200**, from which arrays can be constructed is shown to include a top coil **202** made of a conducting material, preferably a superconducting material and particularly an HTS material. The top coil **202** includes a discontinuity **204** and two outwardly extending protrusions or lands, tags or tabs **206** on opposite sides of the discontinuity **204**. The resonator **200** also includes a bottom, opposing coil **208**, also made of a conducting material, preferably a superconducting material and particularly an HTS material. The bottom coil **208** also includes a discontinuity **210** arranged to be maximally separated from the discontinuity **204** of the top coil **202**, *i.e.*, the bottom or second coil **208** is rotated 180 degrees relative to the first or top coil **202**, thus achieving maximal discontinuity separation. The resonator **200** also includes a dielectric substrate **212** interposed between the two coils **202** and **208** into which the generated electric field is confined. Unlike the top coil **202**, the bottom coil **208** does not include tabs **206**, but instead includes a pair of islands **214** of conductive material positioned in a capacitive relationship to the tabs **206**, *i.e.*, the tabs **206** and the islands **214** with the dielectric **212** therebetween forming capacitors **215**. The resonator **200** also includes a pair of contacts **216** with wires **218** bonded thereto so that the resonator **200** can be connected to a monitoring device such as an MRI imaging device or an NMR instrument. As shown in Figure 2A, the dielectric **212** extends into interior **220** of the resonator **200**. Although this extension is not necessary as shown in **Figures ~~13~~2D-F**, having the dielectric extend into the interior

regions **220** and out past the coils **202** and **208** is a manufacturing convenience and does not adversely affect resonator performance.

[0059] Referring now to **Figures ~~13~~2D-F**, another preferred embodiment of a single resonator of this invention, generally **250**, from which arrays can be constructed is shown to include a top coil **252** made of a conducting material, preferably a superconducting material and particularly an HTS material. The top coil **252** includes a discontinuity **254** and has a general horseshoe shape. The resonator **250** also includes a bottom, opposing coil **258**, also made of a conducting material, preferably a superconducting material and particularly an HTS material. The bottom coil **258** also includes a discontinuity **260**. Thus, in this preferred embodiment, the coils **252** and **258** are identical and are arranged so that the discontinuities **254** and **260** are maximally separated, *i.e.*, the bottom or second coil **258** is rotated 180 degrees relative to the first or top coil **252**, thus achieving maximal discontinuity separation. The resonator **250** also includes a dielectric substrate **262** interposed between the two coils **252** and **258** into which the generated electric field is confined. Unlike the resonator design of **Figures ~~13~~2A-C**, the resonator design of **Figures ~~13~~2D-F** does not include capacitors formed from tabs **206** in the top coil **202** and islands **214** associated with the bottom coil **208**. Instead, a pair of capacitors **264** are formed on the top coil **252** (or the bottom coil **258** not shown) at positions **266** on either side of the discontinuity **204** (**210**). Each capacitor **264** includes a dielectric layer **268** formed on a top surface **270** of the top coil **252** and a conductive layer **272** formed on top of the dielectric layer **268**. The resonator **250** also includes a pair of contacts **274** formed on a top surface **276** of the conductive layer **272** having wires **278** bonded thereto so that the resonator **250** can be connected to a monitoring device such as an MRI imaging device or an NMR instrument. Unlike the resonator **200** of **Figures ~~13~~2A-C**, the dielectric **262** of the resonator **250** does not extends into interior **280** of the resonator **250**. Again, whether the dielectric **212** or **262** extends into the interior **220** or **280** is a matter of design and manufacturing convenience and has no adverse affect on resonator performance.

[0060] Referring now to **Figure ~~13~~2G**, an expanded view of the capacitors **264** are shown, including a portion of the top coil **252**, a portion of the bottom coil **258** and a portion of the dielectric **262**. On the top surface **270** of the top coil **252** is formed the dielectric layer **268** and formed on top of the dielectric layer **268** is the conductive layer **272**. Formed on the top surface **276** of the conductive layer **272** is the contact **274** with the wire **278** extending outward therefrom.

[0061] Referring now to **Figures ~~14~~3A-D**, another preferred embodiment of a single resonator of this invention, generally **300**, from which arrays can be constructed is shown to include a top coil **302** made of a conducting material, preferably a superconducting material and particularly an HTS material. The top coil **302** includes first and second discontinuities **304a&b** and four protrusion or tabs **306** extending out from the discontinuities **304a&b**. The resonator **300** also includes a bottom, opposing coil **308**, also made of a conducting material, preferably a superconducting material and particularly an HTS material. The bottom coil **308** also includes two discontinuities **310a&b**. In this design, the two coils are identical and the discontinuities of each coil are maximally separated. The two coils **302** and **308** are arranged so that all discontinuities **304a&b** and **310a&b** are maximally separated, *i.e.*, the bottom or second coil **308** is rotated 90 degrees relative to the first or top coil **302**, thus achieving maximum discontinuity separation. The resonator **300** also includes a dielectric substrate **312** interposed between the two coils **302** and **308** into which the generated electric field is confined.

[0062] Like the resonator design of **Figures 2D-E**, the resonator design of **Figures ~~14~~3A-D** includes a pair of capacitors **314** formed on the top coil **302** (or on the bottom coil **308** not shown) on the tabs **306**. Each capacitor **314** includes a dielectric layer **316** formed on a top surface **318** of its tab **306** and a conductive layer **320** formed on top of the dielectric layer **318**. The resonator **300** also includes a pair of contacts **322** formed on a top surface **324** of the conductive layer **320** having wires **326** bonded thereto so that the resonator **300** can be connected to a monitoring device such as an MRI imaging device or an NMR instrument.

[0063] As shown in **Figures ~~14~~3A-D**, the dielectric **312** extends into interior **328** of the resonator **300**. Although this extension is not necessary as shown in **Figures 2D-F**, having the dielectric **312** extend into the interior **328** and optionally out past the coils **302** and **308** is a matter of manufacturing convenience and does not adversely affect resonator performance.

[0064] Referring now to **Figures ~~15~~4A-D**, another preferred embodiment of a single resonator of this invention, generally **400**, having a substantially hexagonal shape from which arrays can be constructed is shown to include a top coil **402** made of a conducting material, preferably a superconducting material and particularly an HTS material. The top coil **402** includes three discontinuities **404a-c**. The resonator **400** also includes a bottom, opposing coil **406**, also made of a conducting material, preferably a superconducting material and particularly an HTS material. The

bottom coil **408** also includes three discontinuities **408a-c**. In this design, the two coils are identical and the discontinuities of each coil are maximally separated, *i.e.*, each discontinuity is 120 degrees away from its nearest neighbor; provided, of course, that the current carrier distance between the discontinuities are substantially identical. The two coils **402** and **408** are arranged so that all discontinuities **404a-c** and **410a-c** are maximally separated, *i.e.*, the bottom or second coil **408** is rotated 60 degrees relative to the first or top coil **402**, thus achieving maximum discontinuity separation. The resonator **400** also includes a dielectric substrate **410** interposed between the two coils **402** and **408** into which the generated electric field is confined. One advantage of the hexagonal resonators **400** arrays made from regular hexagons represent a maximum in resonator density for a given surface area.

[0065] Like the resonator designs of **Figures 2D-E** and **Figures 3A-D**, the resonator design of **Figures ~~15~~4A-D** includes a pair of capacitors **412** formed on the top coil **402** (or on the bottom coil **408** not shown). Each capacitor **412** includes a dielectric layer **414** formed on a top surface **416** of its tab **406** and a conductive layer **418** formed on top of the dielectric layer **418**. The resonator **400** also includes a pair of contacts **420** formed on a top surface **422** of the conductive layer **420** having wires **424** bonded thereto so that the resonator **400** can be connected to a monitoring device such as an MRI imaging device or an NMR instrument.

[0066] As shown in **Figures ~~15~~4A-D**, the dielectric **412** extends into interior **426** of the resonator **400**. Although this extension is not necessary as shown in **Figures 2D-F**, having the dielectric **412** extend into the interior **428** and optionally out past the coils **402** and **408** is a matter of manufacturing convenience and does not adversely affect resonator performance.

[0067] Referring now to **Figures ~~16~~5A-B**, another preferred embodiment of a single resonator of this invention, generally **500**, having a circular shape from which arrays can be constructed is shown to include a top coil **502** made of a conducting material, preferably a superconducting material and particularly an HTS material. The top coil **502** includes four discontinuities **504a-d** and eight protrusion or tabs **506** extending out from the discontinuities **504a-d**. The resonator **500** also includes a bottom, opposing coil **508**, also made of a conducting material, preferably a superconducting material and particularly an HTS material. The bottom coil **508** also includes four discontinuities **510a-d**. In this design, the two coils are identical and the discontinuities of each coil are maximally separated, *i.e.*, each discontinuity is 90 degrees away from its nearest neighbor. The

two coils **502** and **508** are arranged so that all discontinuities **504a-d** and **510a-d** are maximally separated, *i.e.*, the bottom or second coil **508** is rotated 45 degrees relative to the first or top coil **502**, thus achieving maximum discontinuity separation. The resonator **500** also includes a dielectric substrate **512** interposed between the two coils **502** and **508** into which the generated electric field is confined.

[0068] Like the resonator designs of **Figures 2D-E**, **Figures 3A-D** and **Figures 4A-D**, the resonator design of **Figures ~~16~~5A-D** includes a pair of capacitors **514** are formed on the top coil **502** (or on the bottom coil **508** not shown) on the tabs **506**.

[0069] As shown in **Figures ~~16~~5A-D**, the dielectric **512** extends into interior **516** of the resonator **500**. Although this extension is not necessary as shown in **Figures 2D-F**, having the dielectric **512** extend into the interior **528** and optionally out past the coils **502** and **508** is a matter of manufacturing convenience and does not adversely affect resonator performance.

[0071] Referring now to **Figures ~~17~~6A-C**, equivalent circuit diagrams for 1 discontinuity per coil resonator, for two 1 discontinuity per coil resonators and three 2 discontinuity per coil resonators. Looking at **Figure 6A**, a 1 discontinuity per coil resonator can be represented by an equivalent circuit, generally **600**. The equivalent circuit **600** includes input outputs **O/P1a&b**, coupling capacitors **CC** with the coils represented by the inductor/capacitor loop **COIL**.

[0077] Referring now to **Figures ~~18~~7A&B**, a preferred embodiment of a linear array comprising two resonators of this invention, generally **700**, is shown to include a pair of resonators **702**. Each resonator **702** includes a top coil **704** and an opposing bottom coil **706** with a dielectric substrate **708** extending out past the resonators **702**. Each of the coils **704** and **706** has a single discontinuity **710** designed therein. The coils **704** and **706** are circular shaped and are arranged in a mirror imaged relationship. Each top coil **704** includes a pair of decoupling capacitors **712** formed thereon on each side of the discontinuities **710**. The resonators **702** also include connecting capacitors (not shown). The array design **700** shows that the decoupling capacitors **712** can be formed on the same side of the resonator. Looking at **Figures 7C**, an alternative array **720** includes bottom coils **722**, a dielectric **724**, top coils **726**, a second dielectric **728** and gold contacts **730**. In this case, tabs **732** form the decoupling capacitors and wings **734** in combination with the gold contacts **730** from the connecting capacitors. Looking at **Figures ~~18~~7D&E**, a preferred embodiment of a linear array comprising two resonators of this invention, generally **750**, is shown to include a pair of resonators **752**. Each

resonator **752** includes a top coil **754** and an opposing bottom coil **756** with a dielectric substrate **758** extending out past the resonators **752**. Each of the coils **754** and **756** has a single discontinuity **760** designed therein. The coils **754** and **756** are square shaped. The resonators 753 are decoupled by a pair of decoupling capacitors **762** formed thereon on each side of the discontinuities **760** by tabs **764**. The resonators **752** also include islands **766** which in conjunction with the tabs 764 can form sites for connecting capacitors (not shown).

[0078] Referring now to **Figures ~~19~~8A&B**, a preferred embodiment of a linear array comprising three resonators of this invention, generally **800**, is shown to include a pair of resonators **802**. Each resonator **802** includes a top coil **804** and an opposing bottom coil **806** with a dielectric substrate **808** extending out past the resonators **802**. Each of the coils **804** and **806** has a single discontinuity **810** designed therein. The coils **804** and **806** are square shaped and include tabs **812** and islands **814** forming decoupling capacitors **816** formed thereon on each side of the discontinuities **810**. Each resonators **802** also include connecting capacitors with wires **818**.

[0079] Referring now to **Figure ~~20~~9**, another preferred embodiment of an MRI or NMR probe of this invention, generally **900**, is shown to include a non-chained, planar or array **902** of a plurality of 2 discontinuity resonators **904** formed into a 3×3 array. Each resonator **904** is made up of a 3×3 array of top coils **911a-919a** having tabs **923, 924, 926** and **927** and a 3×3 array of bottom coils **911b-919b** having tabs **933, 934, 936, 937** and a dielectric substrate **940** interposed therebetween. Overlapping portions of tabs **923, 924, 926, 927 933, 934, 936,** and **937** form the decoupling capacitors as shown in Figure 7E. In the array **900**, each nearest neighbor resonator may be oriented in a plane with a 90 degree offset orientation from its nearest neighbor resonators **904**. Each resonator **904** also includes connecting capacitors **950** formed from dielectric layer **960** deposited on certain of the tabs **923, 924, 926** and **927** and conductive layer **953** and **954** deposited on the dielectric layer **960**.

[0080] Referring now to **Figure ~~21~~10**, a preferred embodiment of an array, generally **1000**, of hexagonal resonators **1002**. Each resonator **1002** includes top and bottom coils **1004** and **1006** having tabs **1008** formed on a dielectric substrate **1010**. Again, overlapping portions of the tabs **1008** on adjacent resonators **1002** form decoupling capacitors **1012**. The resonators **1002** also include connective capacitors with contact **1014** formed on the top coils **1004**. Again, the resonators are preferably made out of HTS and the arrays are preferably operated at or below their T_c. It should

be recognized that the array 1000 can also include other shaped resonators fill all portions of the rectangular surface or can be skewed so that the hexagonal packing is maximal.

[0081] Referring now to **Figure ~~22~~11**, a preferred embodiment of an MRI probe assembly of this invention, generally **1100**, is shown to include a probe **1102** having a housing **1103**, an array **1104** of resonators **1106** of this invention formed on a dielectric substrate **1108** along with pre-amplifiers **1110**, one for each resonator **1106.** The probe assembly **1100** also include a source for cooling **1112** in thermal contact **1114** with the probe **1102** to cool the array **1104** and pre-amplifiers **1110.** The outputs of the pre-amplifiers **1110** are in electrical communication **1116** with an MRI scanner unit **1118.** Preferably, the cooling source **1112** a cryogenic cooling device.

[0082] Referring now to **Figure ~~23~~12**, a preferred embodiment of an MRI apparatus of this invention, generally **1200**, is shown to include a probe **1202** a housing **1203**, having an array **1204** of resonators **1206** of this invention therein and positioned relative to a location **1208** on a human body **1210.** Output signals from the resonators **1206** are transmitted along an output cable **1212** to an amplification unit **1214** including one amplifier for each resonator **1206.** The outputs are then collected, processed and analyzed to produce an image on receiver device **1216.** The probe **1202** is thermally connected via connection **1218** to a source of cooling **1220.** The resonators **1206** receive NMR signals from sample body **1210** and transfer the signals to amplifier **1214.** The signals may then be further communicated to external receiver **1206** where the data may be processed

[0022] The cryogenic housing **1203** may further comprise a heat conductive holder (not shown in the figures), which fixes the array **1204** in predetermined position in cryogenic housing **1203.** The heat conductive holder is made out of heat conductive material, such as copper, sapphire, and the like. The source of cooling **1220** can be a cryogenic fluid circulation system where the connection **1218** is supply and return fluid line or a cold finger where the connection **1218** is simple thermal contact.

The Commissioner is authorized to charge or credit Deposit Account 501518 for any additional fees or overpayments.

Respectfully submitted,

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